

SMART METERING AND DEMAND-SIDE INTEGRATION

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ABSTRACT

Smart metering is the buzz in utility industries (electricity, gas and water) today. Many countries across the globe like Australia, United States of America, India, China, South Africa, etc, are already involved in projects with smart metering on a demonstration scale or implementation. The utility industry is in a phase of rapid change due to rising energy demand, increased number of customers and their demands, market de-regulation, increased cost, energy theft, etc. As a result, the industry has identified demand side management as an essential solution and smart metering is seen as a key component in the implementation of an effective demand side management program.

KEYWORDS: Smart Metering, AMI, DSM, DSI

INTRODUCTION

In many countries, the power infrastructure is ageing and is being increasingly heavily used as demand for electricity rises. This overloading will worsen as large numbers of electric vehicles, heat pumps and other new loads use low-carbon energy from the electric power system. Obtaining planning permission for the installation of new power system equipment, particularly overhead lines, is becoming increasingly difficult. Therefore, demand-side programmes have been introduced widely to make better use of the existing power supply infrastructure and to control the growth of demand. The dual aims of reducing CO₂ emissions and improving energy security (energy policy goals in many countries) coincide in the increasing use of renewable energy for electricity generation. However, connection of a large amount of intermittent renewable generation alters the pattern of the output of central generation and the power flows in both transmission and distribution circuits. One solution to this increase in variability is to add large-scale energy storage devices to the power system. This is often not practical at present due to technical limitations and cost. Therefore, flexibility in the demand side is seen as another way to enable the integration of a large amount of renewable energy. Load control or load management has been widespread in power system operation for a long time with a variety of terminology used to describe it. The name Demand-Side Management (DSM) has been used since the 1970s for a systematic way of managing loads [1]. Demand-Side Integration (DSI) is to refer to all aspects of the relationships between the electric power system, the energy supply and the end-user load. Effective implementation of DSI needs an advanced ICT (Information and Communication Technology) infrastructure and good knowledge of system loads. However, the electro-mechanical meters that are presently installed in domestic/industrial premises have little or no communication ability and do not transmit information of the load in real time. Smart metering refers to systems that measure, collect, analyze, and manage energy use using advanced ICT. The concept includes two-way communication networks between smart meters and various actors in the energy supply system. The smart meter is seen to facilitate DSI through providing real-time or near-real-time information exchange and advanced control capabilities.

SMART METERING

Evolution of Electricity Metering

Electricity meters are used to measure the quantity of electricity supplied to customers as well as to calculate energy and transportation charges for electricity retailers and network operators. The most common type of meter is an accumulation meter, which records energy consumption over time. Accumulation meters in consumer premises are read manually to assess how much energy has been used within a billing period. In recent years, industrial and commercial consumers with large loads have increasingly been using more advanced meters, for example, interval meters which record energy use over short intervals, typically every half hour. This allows the energy suppliers to design tariffs and charging structures that reflect wholesale prices and helps the customers understand and manage their pattern of electricity demand. Smart meters are even more sophisticated as they have two-way communications and provide a real-time display of energy use and pricing information, dynamic tariffs and facilitate the automatic control of electrical appliances. Figure 1 shows the evolution of electrical metering, from simple electro-mechanical accumulation metering to advanced smart metering [6].

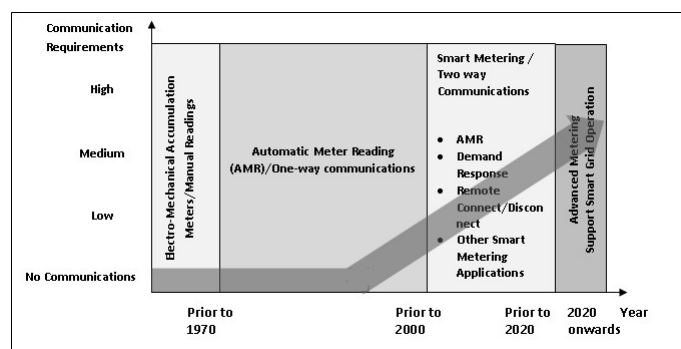


Figure 1: Evolution of Electricity Metering

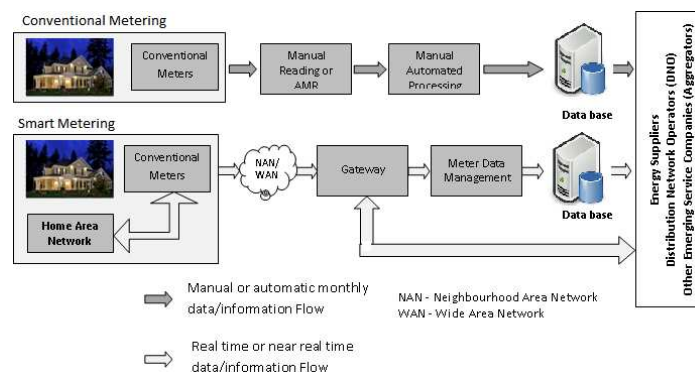


Figure 2: Conventional and Smart Metering Compared

It can be seen from Figure 1 that manual reading was widespread prior to the year 2000. A number of Automatic Meter Reading (AMR) programs were developed around this time where energy consumption information was transmitted monthly from the meters to the energy supplier and/or network operator using low-speed one-way communications networks. Since 2000, there has been a dramatic increase in the performance of the metering infrastructure being installed. One-way communication of meter energy use data, AMR, has given way to more advanced two-way communications supporting applications such as varying tariffs, demand-side bidding and remote connect/disconnect. The Smart Grid vision represents a logical extension of these capabilities to encompass two-way broadband communications supporting a wide range of Smart Grid applications including distribution automation and control as well as power quality monitoring.

The differences between conventional metering and smart metering are shown schematically in Figure 2. Smart meters have two-way communications to a Gateway and/or a Home Area Network (HAN) controller. The Gateway² allows the transfer of smart meter data to energy suppliers, Distribution Network Operators (DNOs) and other emerging energy service companies. They may receive meter data through a data management company or from smart meters directly. The benefits of advanced metering are listed in Table 1. Short-term benefits, particularly for the energy suppliers and metering operators, can be obtained from AMR and Automatic Meter Management (AMM). Longer-term benefits arise from the additional functions of smart metering that lead on to the use of smart meters in the Smart Grid.

Table 1: Benefits of Advanced Metering ^[3]

	Energy Supplies and Network Operator Benefits	All Benefits	Customer Benefits
Short-term	Lower metering costs and more frequent and accurate readings	Better customer service Variable pricing schemes	Energy savings as a result of improved information
	Limiting commercial losses due to easier detection of fraud and theft	Facilitating integration of DG and flexible loads	More frequent and accurate billing
Long-term	Reducing peak demand via DSI programs and so reducing cost of purchasing wholesale electricity at peak time	More reliable energy supply and reduced customer complaints	Simplification of payments for DG output
	Better planning of generation network and maintenance	Using ICT infrastructure to remotely control DG, reward consumers and lower cost of utility	Additional payments for wider system benefits
	Supporting real time system operation down to distribution levels Capability to sell other services (e.g. broadband and video communication)	Facilitating adoption of electric vehicles and heat pumps, while minimum increase in peak demand	Facilitating adoption of home area automation for more comfortable life while minimising energy cost

Key Components of Smart Metering

Smart metering consists of four main components: smart meters, a two-way communication network, a Meter Data Management system (MDM), and HAN. In order to integrate smart metering into the operation and management of the power system, interfaces to a number of existing systems are required, for example, the interface to the load forecasting system, the Outage Management System (OMS), and a Customer Information System (CIS) ^[6]

Smart Meters: An Overview of the Hardware Used

A traditional electro-mechanical meter has a spinning aluminium disc and a mechanical counter display that counts the revolutions of the disc. The disc is situated in between two coils, one fed with the voltage and the other fed with the current of the load. The current coil produces a magnetic field, ϕI and the voltage coil produces a magnetic field, ϕV . The forces acting on the disc due to the interaction between the eddy currents induced by ϕI and the magnetic field ϕV and the eddy currents induced by ϕV and the magnetic field ϕI produce a torque. The torque is proportional to the product of instantaneous current and voltage, thus to the power. The number of rotations of the disc is recorded on the mechanical counting device that gives the energy consumption.

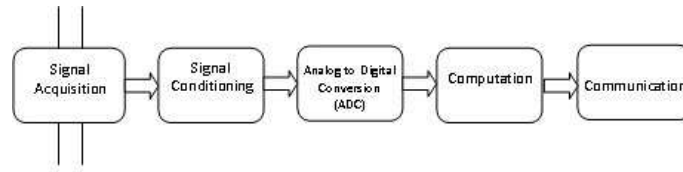


Figure 3: Functional Block Diagram of a Smart Meter

The replacement of electro-mechanical meters with electronic meters offers several benefits. Electronic meters not only can measure instantaneous power and the amount of energy consumed over time but also other parameters such as power factor, reactive power, voltage and frequency, with high accuracy. Data can be measured and stored at specific intervals. Moreover, electronic meters are not sensitive to external magnets or orientation of the meter itself, so they are more tamperproof and more reliable. Early electronic meters had a display to show energy consumption but were read manually for billing purposes. More recently electronic meters with two-way communications have been introduced. Figure 3 provides a general functional block diagram of a smart meter. In Figure 3, the smart meter architecture has been split into five sections: *signal acquisition*, *signal conditioning*, *Analogue to Digital Conversion (ADC)*, *computation* and *communication*.

Signal Acquisition

A core function of the smart meter is to acquire system parameters accurately and continuously for subsequent computation and communication. The fundamental electrical parameters required are the magnitude and frequency of the voltage and the magnitude and phase displacement (relative to the voltage) of current. Other parameters such as the power factor, the active/reactive power, and Total Harmonic Distortion (THD) are computed using these fundamental quantities. Current and voltage sensors measure the current into the premises (load) and the voltage at the point of supply. In low-cost meters the measuring circuits are connected directly to the power lines, typically using a current-sensing shunt resistor on the current input channel and a resistive voltage divider on the voltage input channel (Figure 4).

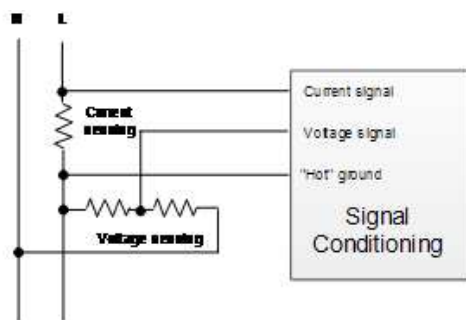


Figure 4: Current and Voltage Sensing

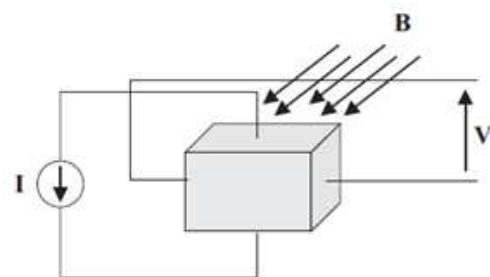


Figure 5: Simplified Diagram of a Hall Effect Sensor [2]

The current sensing shunt is a simple high stability resistor (typically with resistance between $100\mu\Omega$ and $500m\Omega$) with the voltage drop across it proportional to the current flowing through it. The current rating of this shunt resistor is limited by its self-heating so it is usually used only in residential meters (maximum current less than 100 A). In order to match the voltage across the current sensing resistor (which is very small) with the Analogue to Digital Converter (ADC), a Programmable Gain Amplifier (PGA) is used in the signal conditioning stage before the ADC (normally integrated within a single chip with the ADC). The voltage resistive divider gives the voltage between the phase conductor and

neutral. The alloy Manganin is suitable for the resistive divider due to its near constant impedance over typical operating temperature ranges.

A Current Transformer (CT) can also be used for sensing current and providing isolation from the primary circuit. A CT can handle higher currents than a shunt and also consumes less power. The disadvantages are that the nonlinear phase response of the CT can cause power or energy measurement errors at low currents and large power factors, and also the higher meter cost. Some applications may require smart meters with high precision over a wide operating range. For such applications more sophisticated voltage and current measuring techniques such as Rogowski coils, optical methods and Hall Effect sensors may be used. The Hall Effect is a phenomenon in which a magnetic field across a thin conductive material, with a known current flowing (I), causes a voltage (V) across the material, proportional to the flux density (B), as shown in Figure 5. This voltage is measured perpendicular to the direction of current flow. Hall Effect sensors can be used to measure the magnetic field around a conductor and therefore the current flowing within it.

Signal Conditioning

The signal conditioning stage involves the preparation of the input signals for the next step in the process, ADC. The signal conditioning stage may include addition/subtraction, attenuation/ amplification and filtering. When it comes to physical implementation, the signal conditioning stages can be realised as discrete elements or combined with the ADC as part of an Integrated Circuit. Alternatively the stages can be built into a 'System on a Chip' architecture with a number of other functions.

In many circumstances the input signal will require attenuation, amplification or the addition/ subtraction of an offset such that its maximum magnitude lies within the limits of the inputs for the ADC stage. To avoid inaccuracy due to aliasing, it is necessary to remove components of the input signal above the Nyquist frequency (that is, half the sampling rate of the ADC). Therefore, prior to input to the ADC stage, a low pass filter is applied to the signal. The sampling frequency is determined by the functions of the meter. If the meter provides fundamental frequency measurements (currents, voltage and power) and in addition harmonic measurements, then the sampling frequency should be selected sufficiently high so as to obtain harmonic components accurately.

COMMUNICATIONS INFRASTRUCTURE AND PROTOCOLS FOR SMART METERING ^[4]

A typical communications architecture for smart metering is shown in Figure 6. It has three communications interfaces: Wide Area Network (WAN), Neighbourhood Area Network (NAN) and Home Area Network (HAN).

Home-Area Network

A Home-Area Network (HAN) is an integrated system of smart meter, in-home display, microgeneration, smart appliances, smart sockets, HVAC (Heating, Ventilation, Air Conditioning) facilities and plug-in hybrid/electric vehicles. A HAN uses wired or wireless communications and networking protocols to ensure the interoperability of networked appliances and the interface to a smart meter. It also includes security mechanisms to protect consumer data and the metering system. A HAN enables centralized energy management and services as well as providing different facilities for the convenience and comfort of the household. Energy management functions provided by HAN include energy monitoring and display, controlling the HVAC system and controlling smart appliances and smart plugs. The services provided by HAN for the convenience of the household can include scheduling and remote operation of household.

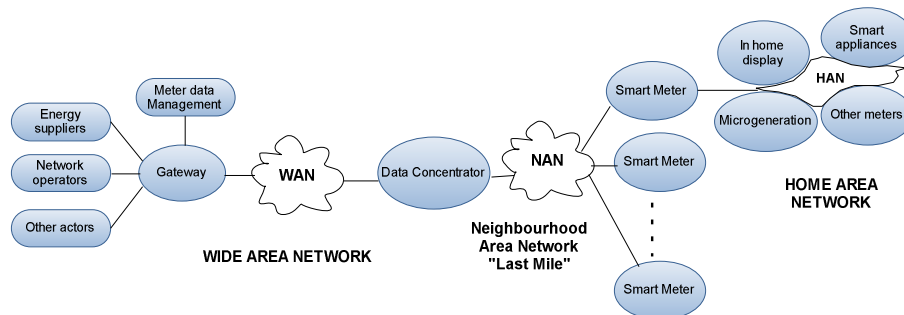


Figure 6: Smart Metering Communication

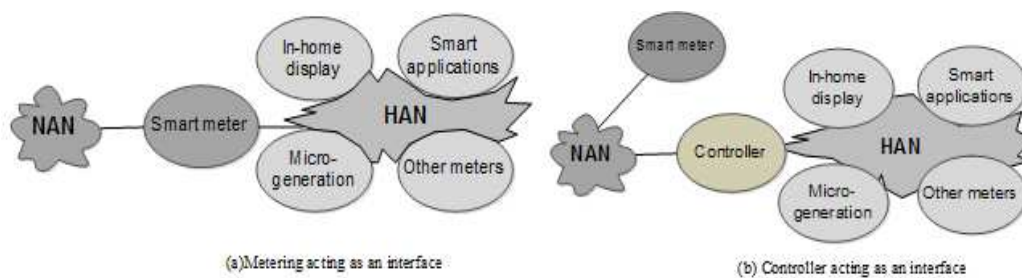


Figure 7: Interface between the HAN and NAN

Appliances as well as household security systems. Home-based multimedia applications such as media centres for listening to music, viewing television and movies require broadband Internet access across the HAN. A separate HAN used for energy services can coexist with the broadband Internet system but there is some expectation that the systems will be merged in the future. It is expected that HAN will provide benefits to the utilities through demand response and management and the management of micro-generation and the charging of electric vehicles. In order to provide demand management functions and demand response, two options are being actively considered in different countries (Figure 7). One option is to use the smart meter as the interface to the suppliers, network operators and other actors. The other option is to use a separate control box [7, 8] which is directly interfaced to the outside world through the NAN and WAN.

Neighborhood Area Network

The primary function of the Neighborhood Area Network (NAN) is to transfer consumption readings from smart meters. The NAN should also facilitate diagnostic messages, firmware upgrades and real-time or near real-time messages for the power system support. It is anticipated that the data volume transferred from a household for simple metering is less than 100 kB per day and firmware upgrades may require 400 kB of data to be transferred. However, these numbers will escalate rapidly if different real-time or near real-time smart grid functions are added to the smart metering infrastructure. The communication technology used for the NAN is based on the volume of data transfer. For example, if ZigBee technology which has a data transfer rate of 250 kb/s is used, then each household would use the communication link only a fraction of a second per day to transfer energy consumption data to the data concentrator.

Data Concentrator

The data concentrator acts as a relay between the smart meters and the gateway. It manages the meters by automatically detecting them, creates and optimises repeating chains (if required to establish reliable communication), coordinates the bi-directional delivery of data, and monitors the conditions of the meters.

Meter Data Management System

The core of a meter data management system is a database. It typically provides services such as data acquisition, validation, adjustment, storage and calculation (for example, data aggregation), in order to provide refined information for customer service and system operation purposes such as billing, demand forecasting and demand response. A major issue in the design and implementation of a meter data management system is how to make it open and flexible enough to integrate to existing business/enterprise applications and deliver better services and more value to customers while ensuring data security. Besides the common database functionalities, a meter data management system for smart metering also provides functions such as remote meter connection/disconnection, power status verification, supply restoration verification and on-demand reading of remote smart meters.

Protocols for Communications

Currently various kinds of communication and protocol types are used for smart metering. Table 2 summarizes the characteristics of the most commonly used protocols for demand side applications, including local AMR, remote AMR, smart metering and home area automation. In Table 2, 'Y' means applicable, and a blank means not applicable or the information is still not available. With local AMR, the meter readings are collected by staff using hand-held devices and with remote AMR the meter readings are collected from a distance through communication links. For most protocols listed in Table 2, the data frame size is also shown. The important factors for consideration when assessing communication protocols for smart metering are summarised in Table 2.

Table 2: Main Smart Metering Protocols

Protocol	Local AMR	Remote AMR	Smart Metering	HAN	Estimated Frame Size (Bytes)
TCP/IP		Y	Y	Y	50
IEC 62056	Y	Y	Y	Y	14
SML	Y	Y	Y	Y	14
IEC 61334 PLC		Y	Y		45
EN 13757 M-Bus	Y	Y	Y	Y	27
SITRED	Y	Y	Y		45
PRIME	Y	Y	Y		8
Zigbee Smart Energy			Y	Y	25
EverBlu	Y	Y	Y		
OPERA/UPA		Y	Y		24
IEC 62056-21 'FLAG'	Y	Y			22
IEC 62056-21 'Euridis'	Y	Y			45
ANSI C12.2		Y	Y		64

Table 3: Important Factors for Assessment of Smart Metering Communication Protocols

Criteria	Description
Openness	Availability of protocol specifications Status of controlling body
Interoperability Scalability/Adaptability Intended function	Extent of ability to interact with other standards, applications and protocols Ease with which the protocol can be extended or changed The intended function of the smart meter such as communicating data to a central entirely for billing or communicating data to a third party for other market

	operations
Maturity	The stage at which the protocol is in its development
Performance	The speed and efficiency with which the protocols operate
Security	Existence of known security vulnerabilities

DEMAND-SIDE INTEGRATION ^[11]

Demand-Side Integration (DSI) is a set of measures to use loads and local generation to support network operation/management and improve the quality of power supply. DSI can help defer investment in new infrastructure by reducing system peak demand. In practice, the potential of DSI depends on: availability and timing of information provided to consumers, the duration and timing of their demand response, performance of the ICT infrastructure, metering, automation of end-use equipment and pricing/contracts. There are various terms in use in the demand side, whose meanings are closely related to each other but with slightly different focuses. Some widely used definitions are:

- **Demand-Side Management (DSM):** utility activities that influence customer use of electricity. This encompasses the planning, implementation and monitoring of activities designed to encourage consumers to change their electricity usage patterns.
- **Demand Response (DR):** mechanisms to manage the demand in response to supply conditions.
- **Demand-Side Participation:** a set of strategies used in a competitive electricity market by end-use customers to contribute to economic, system security and environmental benefits.

Services Provided by DSI

Demand-side resources such as flexible loads, distributed generation and storage can provide various services to the power system by modifying the load consumption patterns. Such services can include load shifting, valley filling, peak clipping, dynamic energy management, energy efficiency improvement and strategic load growth [1, 12]. Simple daily domestic load profiles are used to illustrate the function of each service, as shown in Figures 8-11.

Load shifting is the movement of load between times of day (from on-peak to off-peak) or seasons. In Figure 8, a load such as a wet appliance (washing machine) that consumes 1 kW for 2 hours is shifted to off-peak time. Figure 9 shows the main purpose of **valley filling**, which is to increase off-peak demand through storing energy, for example, in a battery of a plug-in electric vehicle or thermal storage in an electric storage heater. The main difference between valley filling and load shifting is that valley filling introduces new loads to off-peak time periods, but load shifting only shifts loads so the total energy consumption is unchanged (as shown in Figure 8). **Peak clipping** reduces the peak load demand, especially when demand approaches the thermal limits of feeders/transformers, or the supply limits of the whole system. Peak clipping (Figure 10) is primarily done through direct load control of domestic appliances, for example, reducing thermostat setting of space heaters or control of electric water heaters or air-conditioning units. As peak clipping reduces the energy consumed by certain loads (in Figure 10, 2 kWh of energy is reduced), often consumers have to reduce their comfort. Energy efficiency programs are intended to reduce the overall use of energy. Approaches include offering incentives to adopt energy-efficient appliances, lighting, and other end-uses; or strategies that encourage more efficient electricity use, for example, the feedback of consumption and cost data to consumers, can lead to a reduction in total energy consumption.

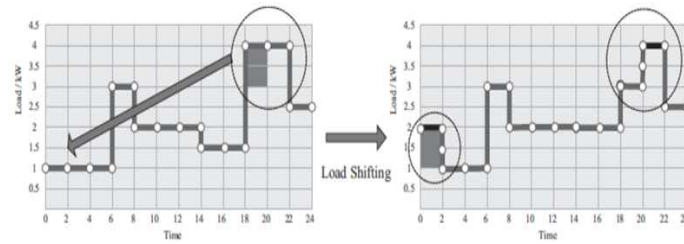


Figure 8: Load Shifting

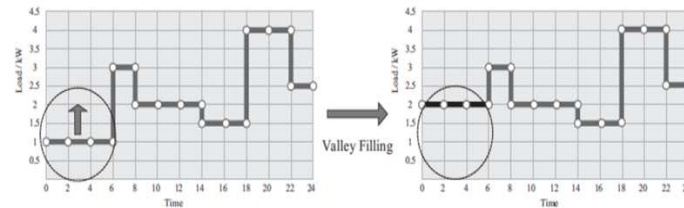


Figure 9: Valley Filling

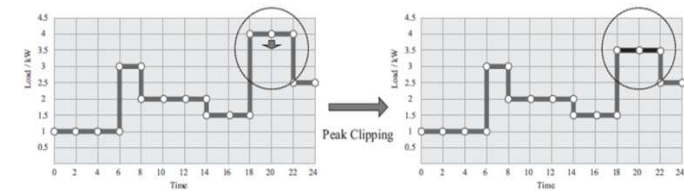


Figure 10: Peak Clipping

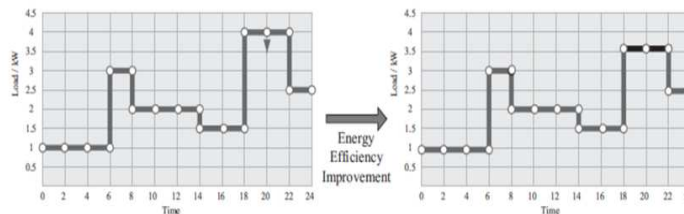


Figure 11: Energy Efficiency Improvement

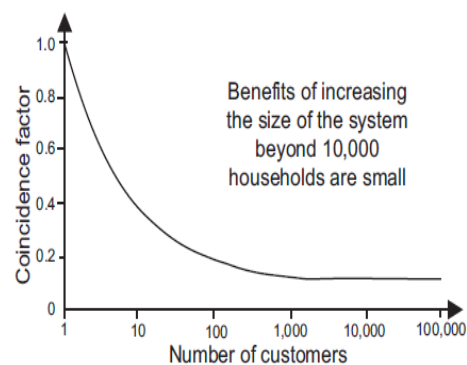


Figure 12: Reduction of Coincidence Factor with Number of Domestic Customers

Figure 11 shows the reduction in energy demand when ten 60 W filament lamps (operating from 18.00 hrs to 22.00 hrs) are replaced by 20 W Compact fluorescent lamps. With the deployment of smart metering and the development of home area automaton technologies, domestic appliances can be controlled in a more intelligent way, therefore bringing

more flexibility to the demand side. The load shape is then flexible and can be controlled to meet the system needs. However, for the most effective DSI, the utility needs to know not only which loads are installed in the premises but which are in use. In this case two-way communication between the smart meter and network operators is necessary. One way to de-carbonize the heating and transportation sectors is through electrification, for example, the increased utilization of heat pumps and plug-in electric vehicles. However, the immediate consequence is the increase in electricity load causing potentially serious operational problems to both distribution and generation systems. Appropriate control and management are required if plant is not to be overloaded. Demand-Side Integration describes a set of strategies which can be used in competitive electricity markets to increase the participation of customers in their energy supply. When customers are exposed to market prices, they may respond as described above, for example, by shifting load from the peak to the off-peak period, and/or by reducing their total or peak demand through load control, energy-efficiency measures or by installing distributed generation. Customers are able to sell energy services either in the form of reductions in energy consumption or through local generation. Traditionally electric power systems were designed assuming that all loads would be met whenever the energy is requested. Domestic customers (and many other loads) use electricity at different times and this allows the design of the power system to benefit from diversity. For example, although a house in England may draw up to 10 kW at some times, its distribution supply system will be designed on an After Diversity Maximum Demand (ADMD) of only 1 or 2 kW. The coincidence of domestic demand follows the shape of Figure 12 and although distribution networks may only serve, say, 100 customers the transformers and cables also have significant thermal inertia and so a further reduction in the rating used for design may be assumed. Demand-Side Integration has the potential to negate the beneficial effects of diversity. Consider a peak clipping control that sends a signal to switch off one hundred 3 kW water heaters that operate under thermostatic control. Although 100 water heaters have been installed, only, say, 20 will be drawing power at any one time. Thus the peak will be reduced by 60 kW. When, after, say, two hours, the water heaters are reconnected, all the water tanks will have cooled and a load of 300 kW will be reconnected. Thus DSI measures must consider both the disconnection of loads but also their reconnection and the payback of the energy that has not been supplied. It is much easier to manage both the disconnection of loads and their reconnection with bi-directional communications whereby the state of the loads can be seen by the control system.

Implementations of DSI

The implementations of DSI can be through price-based schemes or incentive-based schemes [13]. Price-based DSI encourages customer load changes in response to changes in the electricity price. Incentive-based DSI gives customers load modification incentives that are separate from, or in addition to, their retail electricity rates. Various DSI programs are deployed and integrated within the power system core activities at different time scales of power system planning and operation, as shown in Figure 5.20.

Price-Based DSI Implementations

Tariffs and pricing can be effective mechanisms to influence customer behavior, especially in unbundled electricity markets. Price schemes employed include time of use rates, real-time pricing and critical peak pricing:

- **Time of Use (ToU):** ToU rates use different unit prices for different time blocks, usually pre-defined for a 24-hour day. ToU rates reflect the cost of generating and delivering power during different time periods.

- **Real-Time Pricing (RTP):** the electricity price provided by RTP rates typically fluctuates hourly, reflecting changes in the wholesale electricity price. Customers are normally notified of RTP prices on a day-ahead or hour-ahead basis.
- **Critical Peak Pricing (CPP):** CPP rates are a hybrid design of the ToU and RTP. The basic rate structure is ToU. However, the normal peak price is replaced by a much higher CPP charge in quantity demanded in response to a 1 per cent change in price (holding constant all the other determinants of demand).

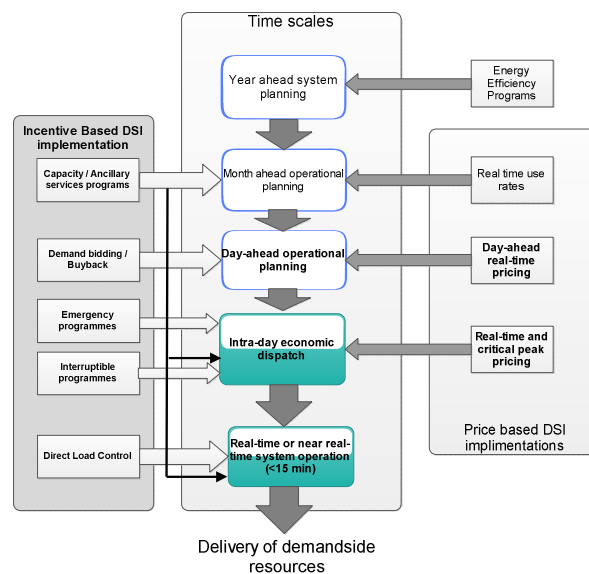


Figure 13. Deployment of DSI Programs at Different Time Scales

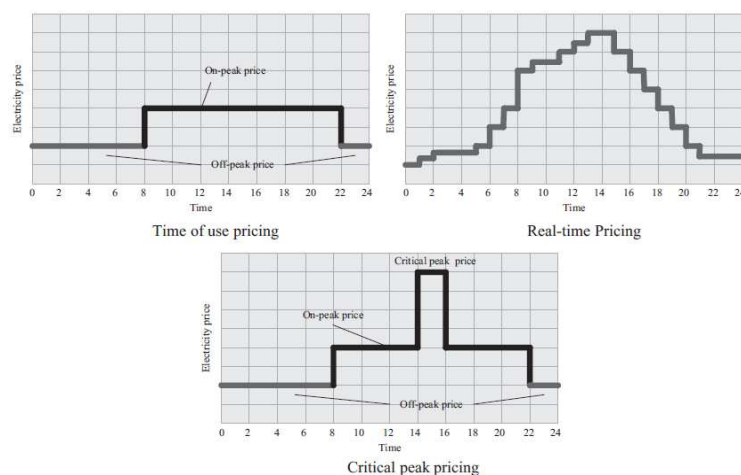


Figure 14: Illustration of Various Pricing Schemes

There are different 'elasticity's' in use to evaluate the available amount of the demand-side resources:

- **Price Elasticity of Demand:** The percentage of change in demand as a result of a percentage of change in price (the elasticity should be a negative number)

$$\text{Price Elasticity} = \frac{\Delta D / D}{\Delta P / P}$$

where D is the demand, ΔD is the change in customer demand, P is the price, and ΔP is the change in the electricity energy price.

- **Elasticity of Substitution:** Is a measure of the percentage change in the ratio of the peak to off-peak demand as a result of a percentage change in the ratio of the peak to off-peak price.
- **Long-Term Price Elasticity:** Is the annual energy consumption response to an average change in energy price.

Incentive-Based DSI Implementations: Table 4 Lists Various Kinds of Implementations of Incentive-Based DSI

Table 4: Implementations of Incentive-Based DSI

Implementations	Descriptions
Direct load control	Customers electrical appliances (e.g. air conditioner, water heater, space heating) are controlled remotely (for example, shut down or tuned by the controller) by the program operator on short notice. Direct load control programme are primarily offered to residential or small commercial customers
Interruptible/curtailable service	Curtailment options integrated into retail tariffs providing a rate discount or bill credit for agreeing to reduce load during system contingencies. Penalties may be introduced for failing to curtail
Demand-side bidding/ Buy-back programs	Customers offer bids for curtailment based on wholesale electricity market prices Mainly offered to large customers (for example, one megawatt and over)
Emergency demand response programs Capacity market programs	Provide incentive payments to customers for load reduction during periods when the system is short of reserve Customers offer load curtailment as system capacity to replace conventional generation Customers typically receive intra-day notice of curtailment events Incentives usually consist of upfront reservation payments, and penalties for customer failure to curtail.
Ancillary services market programs	Customers bid load curtailments in ISO /RTO (Independent System Operator/Regional Transmission Organisation) markets as operational reserves If their bids are accepted, they are paid the market price for committing to be on standby If their load curtailments are needed, they are called by the ISO/RTO, and will be paid the spot market energy price

HARDWARE SUPPORT TO DSI IMPLEMENTATIONS

The essential ICT infrastructure required for DSI can be provided by smart metering. In addition, load control switches, controllable thermostats, lighting controls and adjustable speed drives are required. Such equipment receives signals such as alarms or price signals and controls loads accordingly.

Load Control Switches

A load control switch is an electronic apparatus which consists of a communication module and a relay. It is wired into the control circuit of an air conditioning system, a water heater or a piece of thermal comfort equipment. The communication module is used to receive control Smart Grid: Technology and Applications signals from the DSI

program operator (or a HAN). The time that the appliance will remain disconnected is generally pre-programmed (through an inbuilt clock).

Controllable Thermostats

This type of apparatus combines a communication module with a controllable thermostat, and replaces conventional thermostats such as those on air conditioning systems or water heaters. The DSI program operator (or a HAN) can increase or decrease the temperature set point through the communication module, changing the functioning of the equipment and hence the electricity load.

Table 5: Lighting Control Strategies ^[7]

Strategy	Description	Estimated Energy Savings
Planning program	Elimination or reduction of lighting during periods of low occupancy	10–30% with programmers 30–60% with personnel detectors
Natural lighting	Deactivation or dimming of lighting according to the natural lighting in the building	10–15% for deactivation 15–35% for dimming
Constant light levels	Efficient compensation of low levels of natural light	10–15%
Tuning	Tuning the level of lighting according to the needs of the area	10–20%
Load shedding	Temporary lighting reduction to reduce peak demand	-
Light compensation	Modification of the level of lighting for increased visual comfort	-

Lighting Control

Lighting control equipment is used to manage the energy used by lighting in a more efficient way. Lighting control strategies for energy consumption reduction are listed in Table 5. Estimated energy savings are presented for each case. These savings are based upon estimated average consumption, the time of use and user behavior.

Adjustable Speed Drives

Adjustable Speed Drives (ASDs) allow electric motors driving pumps, ventilation units and compressors to function over a continuous speed range. The loads of the majority of motorized appliances change over time and equipment is often operated at less than full load. ASDs allow the motors to satisfy the required functioning conditions and to economize power and energy use when the system is not functioning at its maximum load. Directly connected motors for pump and fans are often oversized and the fluid flow throttled for control. Replacement of this system by an ASD can yield considerable saving of energy.

Flexibility Delivered by Prosumers from the Demand Side

Some customers have installed Distributed Generation (DG) and energy storage (these are generally referred to Distributed Energy Resources – DERs) in their premises. Such customers not only consume electricity, but also are able to manage their capacity to supply power to the grid. Hence they are also called prosumers. The controllability of active power is fundamental for the commercial integration of prosumers. The controllability of reactive power of distributed energy resources has a great influence on the fault ride-through capability and the provision of ancillary services. The flexibility provided by prosumers depends on the level of DER penetration, the DER technologies utilised, and the

locations and interfacing technologies of the connection points with the power network. DER connected to low and medium voltage levels will have more opportunities to provide local network services than generation connected at higher voltage distribution networks.

System Support from DSI

Emergency load shedding has been used in many power systems to maintain the integrity of the power system in the event of a major disturbance. It is triggered by under-frequency relays when the frequency drops under a certain threshold, for example, 48.8 Hz in England and Wales, and consists of the tripping of entire distribution feeders. Load shedding is planned by the TSO but is implemented by the DNOs who arrange the tripping of distribution feeders and choose which feeders are tripped. During normal operation, the GB Transmission System Operator (NGET) maintains the frequency at 50 ± 0.2 Hz. In order to maintain frequency, NGET buys frequency response services. When the frequency goes up, high frequency response is used to reduce the power output of the large generators and hence the frequency. A sudden drop in frequency is contained using primary response (Figure 15). This should be delivered within 10 seconds and maintained for another 20 seconds [15]. The system frequency is brought back to normal using secondary response which lasts from 30 seconds to 30 minutes. If the frequency continues to drop below 48.8 Hz, demand is disconnected (load shedding) to prevent shutdown of the power system [16]. Primary and secondary response is usually provided by partially loaded generators increasing their output. However, this incurs significant costs as de-loading a steam turbine set by, for example, 100 MW only provides around 20 MW of primary response. Primary response requires energy to be used that is stored as high pressure steam in the boiler drum and so only a fraction of the de-loaded power can be used. Operating a steam turbine set at below its maximum output significantly reduces its thermal efficiency.

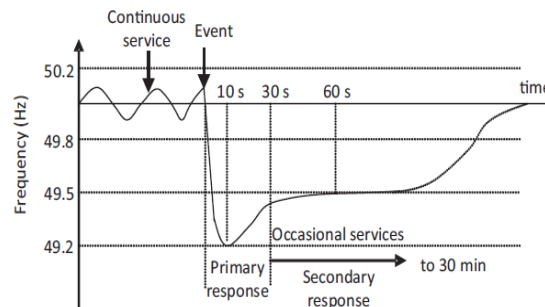


Figure 15: Typical Examples of Frequency Control

DSI programs can significantly reduce the requirement for primary and secondary responses from partially loaded generators by shedding load in a controlled manner. Large loads that are contracted to provide frequency response are typically steelworks or aluminium smelters though hospitals and banks that have their own generators can also take part in this market. Using load in this way reduces the system operating cost and, depending on the alternative generation being used, CO₂ emissions. Recent consultations issued in the UK indicate that smart meters will have the capability for Direct Load Control (DLC). DLC directly switches off loads to balance supply and demand during emergency conditions such as sudden loss of generation. In the USA, DLC has been used by power system operators or by companies which provide DSI services.

AMI Penetration Rate^[10]

The automated metering infrastructure (AMI) describes in this paper the capability of the system to actively manage the demand side. The AMI penetration (%) represents the share of end users connected to the electricity grid through smart meters. This equipment enables dynamic pricing of electricity by measuring the consumption in hourly or smaller intervals. This device could also communicate with in-home display within the customer premises and display real-time consumption and price of the electricity. Smart meters without dynamic electricity rates, however, provide no incentive to manage peak. This study assumes that dynamic pricing will be adopted following the installation of smart meters and AMI. In order to evaluate the potential impact on peak demand, the share of smart meters installed is introduced as an auxiliary variable to measure the deployment of AMI. Aggressive smart meter adoption programmes are being launched throughout all analyzed regions. The implementation of smart meters can be assumed to follow the shape of a logistic curve with exponential growth initially, followed by a slowing growth and finally reaching maturity as most households are equipped with smart meters. Thus, deployment of AMI can be represented by the following equations:

$$\frac{dAMI}{dt} = r * STEP(T_{DR} - T_{lag}) * AMI(t) * (1 - AMI(t))$$

The coefficient r is the growth rate. The step function $STEP$ is assumed to trigger at a fixed time interval (T_{Lag}) before the moment at which demand response (T_{DR}) is in operation, with T_{Lag} assumed to be five years. The $STEP$ function in the above discussion is defined as:

$$STEP = \begin{cases} 0 & \text{if } T_{DR} - T_{lag} < 0 \\ 1 & \text{if } T_{DR} - T_{lag} \geq 0 \end{cases}$$

Most governments of the regions analyzed have recently launched smart meter deployment programmes (Table 6).

Table 6

Regions	Countries	Smart Meter Projections
OECD EUR	Italy ^A Finland ^B United Kingdom ^C France ^D Ireland ^E European Union ^F	100% today 80% by 2014 100% by 2019 95% by 2016 100% by 2017 80% by 2020
OECD NA	United States ^G Canada ^{H,I}	40 million≈33% by 2015 Ontario: 100% by 2010 British Columbia: 100% by 2012
OECD PAC	Australia ^J Japan Korea ^K	100% by 2015 100% by 2020 100% by 2020
China		100% by 2020/2025

Sources: (A) ENEL (n.d.); (B) Ministry of Trade and Industry, Finland, 2009; (C) Department of Energy and Climate Change, UK, 2011; (D) Ministry of Ecology and Energy, France, 2010; (E) Commission for Energy Regulation, Ireland, 2011; (F) European Commission, 2009; (G) Ernst & Young (n.d.); (H) Ministry of Energy, Ontario (n.d.); (I) BC Hydro, 2011; (J) Budde, 2010; (K) MKE, 2010.

Smart Grid: Indian Scenario

The India Smart Grid Task Force is an inter ministerial group and will serve as government focal point for activities related to SMART GRID. The Main functions of ISGTF pertaining to Smart Grid are:

- To ensure awareness coordination and integration of diverse activities related to Smart Grid Technologies.
- Practices & services for research & development of SMART GRID.
- Coordination and integrate other relevant inter governmental activities.
- Collaborate on interoperability framework.
- Review & validate recommendations from India Smart Grid Forum etc.

The Ministry of Power, Govt of India has launched a pilot projects on Smart Grids in various state of India. The various Smart Grid Projects which are undertaken are as shown in below table:

Table 7: Smart Grid Pilot Projects in Power Distribution Sector in India

S.No.	Utility Name	Area Proposed	Functionality Proposed*	Initial Consumer Base
1	CESC, Mysore, Karnataka	Mysore Additional City Area Division	AMI R, AMI I, OM, PLM, MG/ DG	21,824
2	APCPDCL, Andhra Pradesh	Jeedimetla Industrial Area	AMI R, AMI I, PLM, OM, PQM	11,904
3	APDCL, Assam	Guwahati Project Area	PLM, AMI R, AMI I, OM, DG, PQM	15,000
4	UGVCL, Gujarat	Naroda / Deesa	AMI R, AMI I, OM, PLM, PQM	39,422
5	MSEDCL, Maharashtra	Baramati, Pune	AMI R, AMI I, OM	25,629
6	UHBVN, Haryana	Panipat City SubDivision	AMI R, AMI I, PLM	30,544
7	TSECL, Tripura	Electrical Division No. I, Agartala	AMI R, AMI I, PLM	46,071
8	HPSEB, Himachal Pradesh	ESD Kala Amb Under Electrical Division, Nahan	AMI I, OM, PLM, PQM	650
9	Puducherry	Div 1 of Puducherry	AMI R, AMI I	87,031
10	JVVNL, Rajasthan	VKIA Jaipur	AMI R, AMI I, PLM	2,646
11	CSPDCL, Chattisgarh	Siltara, Chattisgarh	AMI I, PLM	508
12	PSPCL, Punjab	Mall Mandi City Sub-Division Amritsar	OM	9,000
13	KSEB, Kerala	AMII I	AMI I	25,078
14	WBSEDCL, West Bengal	Siliguri town, Darjeeling District	AMI R, AMI I, PLM	4,404

*Legend:

S.No.	Functionality Abbreviation	Functionality
1	AMI R	Advanced Metering Infrastructure for Residential Consumers
2	AMI I	Advanced Metering Infrastructure for Industrial Consumers
3	OM	Outage Management
4	PLM	Peak Load Management
5	PQM	Power Quality Management
6	MG	Micro Grid
7	DG	Distributed Generation

Source: Ministry of Power, Govt of India

Smart Grid: World Scenario

Australian Government has initiated, and is currently funding the Smart Grid, Smart Cities (SGSC) Trial. It aims to test several hypotheses about many types of Smart Grid technology. In particular, the Trial aims to quantify the following seven benefits of energy storage:

- **Reduction in Peak Demand:** energy storage as a cost-effective and reliable alternative to network capacity expansion
- **Improvement in Network Reliability/Voltage/Power Factor/Power Quality:** cost-effectiveness and value of energy storage
- **Energy Supply During Peak Price Events:** net benefit to retail sector
- **Minimisation of Customers' Energy Bills:** with innovative tariffs e.g. time of use together with energy storage.

- Combined benefit between consumer, retail and network sectors
- **Investigation of Large Capacity (~1 MVA) Storage:** extra cost and other benefits compared to smaller capacity storage
- Intermittent generation support optimisation of renewable energy sources value

Virginia Dominion Power

This utility intends install \$600 million worth of equipment to create a smart grid. First Dominion installed 30,000 smart meters, and then invested \$1.5 million in synchrophasors - devices installed at substations which monitor grid conditions. This real-time data helps utilities transmit more electricity across a high-voltage grid. The operational efficiencies derived from a smarter power distribution and transmission system, coupled with Dominion's EDGE conservation voltage reduction program, are yielding real savings. This smart grid implementation is expected to save more than \$1 billion over the project's life of 15-20 years, against Dominion's \$600 million investment: a 67% ROI. Plus this program will yield environmental and societal benefits, such as avoiding the construction of two power plants, and delaying the construction of two more. (Source: <http://www.emeter.com/smart-grid-watch>)

CONCLUSIONS

This paper has analysed the smart grid drivers in the context of Smart metering and demand side management. A smart grid replaces analog mechanical meters with digital meters that record usage in real time. Smart meters are similar to Advanced Metering Infrastructure (AMI) meters and provide a communication path extending from generation plants to electrical outlets (smart socket) and other smart grid-enabled devices. The paper also highlights the short, medium long term benefits of Advanced Metering. Effective implementation of DSI needs an advanced ICT (Information and Communication Technology) infrastructure and good knowledge of system loads. However, the electro-mechanical meters that are presently installed in domestic premises have little or no communication ability and do not transmit information of the load in real time. Smart metering refers to systems that measure, collect, analyse and manage energy use using advanced ICT. The concept includes two-way communication networks between smart meters and various actors in the energy supply system. The smart meter is seen to facilitate DSI through providing real-time or near-real-time information exchange and advanced control capabilities.

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